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Heteroscedasticity,  
and Contagion Measurement:  
MS-VAR Application of the DCC Procedure**

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# **Tranquil and Crisis Windows, Heteroscedasticity, and Contagion Measurement: MS-VAR Application of the DCC Procedure**

Victor Pontines<sup>a</sup> and Reza Y. Siregar<sup>b</sup>

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## **Abstract:**

The key objective of this study is to show that two potential shortcomings of the Determinant of Change in Covariance Matrix (DCC) procedure of Rigobon (2003), namely with the arbitrary determination of the windows, i.e., tranquil and crisis periods and the violation of its heteroscedasticity assumption under the null, can be simultaneously addressed via a simple incorporation of a Markov-Switching Vector Autoregressive (MS-VAR) approach into the overall DCC procedure. To demonstrate this, we revisit the period around the time of the East Asian crises using daily stock exchange of Indonesia, Malaysia, Philippines, Thailand, Singapore, Korea, Hong Kong and Taiwan and test whether there is a significant break or discontinuity in the stock exchange returns of the eight East Asian markets during crisis periods, especially around the time of the 1997 financial crises. In contrast to that of Rigobon (2003), our results show that the propagation of shocks shifted significantly starting with the onset of the sharp decline in the Hong Kong stock market.

**Keywords:** Contagion; Markov-Switching Vector Autoregressive; Determinant of the Change in the Covariance Matrix; and Stock Returns.

**JEL Classification:** C32, F02, G15

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<sup>a</sup>/ Carnegie Mellon University, H. John Heinz III School of Public Policy and Management, Australia, 220 Victoria Square Adelaide SA 5000 Australia, E-mail: pontines@andrew.cmu.edu

<sup>b</sup>/ Corresponding Author. The School of Economics, University of Adelaide and the IMF-Singapore Regional Training Institute, E-mail: [reza.siregar@adelaide.edu.au](mailto:reza.siregar@adelaide.edu.au)

## 1. Introduction

During currency and financial crises such as that of the Mexican, East Asian and Russian/Long-Term Capital Management (LTCM) crises, asset prices comovements across markets tend to increase visibly compared with more tranquil periods. The size of these comovements and the processes that generated them, have driven the literature to ask exactly on whether tranquil periods and crisis are to be interpreted as different regimes in the international transmission of financial shocks—that is, whether there are breaks or discontinuities in cross-market linkages.

The debate starts with the seminal work of King and Wadhwani (1990) which used a straightforward approach to test for contagion to looked for evidence of a sharp increase in the correlations between stock market returns of the United States, the United Kingdom, and Japan after the US stock market crash of 1987. Subsequent studies, applying this approach of finding a marked increase in cross-market correlations, especially in times of financial stress, have come to be known in the contagion literature as ‘correlation breakdown’ studies.<sup>1</sup>

However, the finding of a dramatic increase in cross-market correlations during the volatile period of financial crisis has not gone unchallenged. Building on an earlier seminal work by Ronn (1998), a number of studies, in particular, Boyer et al. (1999), Loretan and English (2000), Forbes and Rigobon (2002) have argued that the presence of heteroscedasticity in market returns have a significant impact on estimates of cross-market correlation coefficients, due to what is referred to as *heteroscedasticity bias*. That is, during times of heightened market volatility, cross-market correlation coefficients have a tendency

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<sup>1</sup> See Lee and Kim (1993), Calvo and Reinhart (1996), Frankel and Schmukler (1996), Valdez (1997), Baig and Goldfajn (1999), and Agenor, Aizenman, and Hoffmaister (1999). See Pericolli and Sbracia (2003) for the usage of the terms ‘correlation breakdowns’.

to increase substantially as well. For instance, an examination of the period from early 1998 to a couple of months after the Russian default in August 1998, a comprehensive study done by the Bank for International Settlement (BIS) found that the average correlation between five-day changes in yield spreads for 26 instruments in 10 economies increased substantially from 0.11 in the first half of 1998 to 0.37 for the period of August 17-September 22, 1998 (BIS, 1999).

The marked rise in the cross-market correlation coefficients may suggest that contagion has occurred, even if there is no change in the underlying transmission mechanism between markets. In fact, once cross-market correlation coefficients are corrected or adjusted for heteroscedasticity, evidence of contagion disappeared in almost all cases. This led Forbes and Rigobon (2002) to assert the well-known phrase, 'no contagion, only interdependence'. Nonetheless, their study has also argued that the adjustment in the correlation coefficient requires restrictive heteroscedasticity assumptions, and the measure is biased in the presence of simultaneous equations and omitted variable problems in the data.<sup>2</sup>

In a follow-up paper, Rigobon (2003) attempted to deal with the aforementioned econometric problems that arise in stock market returns data by introducing a new procedure called the DCC (Determinant of the Change in the Covariance matrix) test. The procedure was applied to examine whether transmissions of shocks across countries intensified during the Mexican (1994-95), East Asian (1997-98) and Russian (1998) crises.

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<sup>2</sup> In addition, Dungey and Zhumabekova (2001) emphasised that the adjustment in the correlation coefficient suffers from low power when typically dealing with a relatively small crisis sample. More recently, Corsetti, et al. (2005) assert that the results obtained by Forbes and Rigobon (2002) of the lack of evidence of contagion in almost all cases can be attributed to arbitrary assumptions on the variance of the market-specific noise in the country where the crisis started. As they demonstrate, the adjustment in the correlation coefficient is biased towards the null hypothesis of interdependence, that is, the null hypothesis is erroneously accepted in a number of cases, when it should be rejected in favour of contagion.

The study obtained results which suggests that the propagation mechanisms of 36 stock markets remained relatively stable throughout the three recent major international crises, suggesting no evidence of contagion, only that of interdependence.

However, recent studies question the effectiveness of the DCC procedure for distinguishing breaks in linkages between markets during a crisis. In particular, Billio, Duca and Pelizzon (2003) showed two potential shortcomings of the original application of the DCC in Rigobon (2003).<sup>3</sup>

- (i) First, the DCC test lacks power in a multivariate setting, which they believe to be due to its ad-hoc process in determining the window periods (tranquil and crisis windows).
- (ii) Second, the DCC procedure does not allow one to distinguish whether rejections of the null of stability are due to parameter shift (case of contagion) or to a violation of its heteroscedasticity assumption under the null.

In light of the problems above, Billio, Duca and Pelizzon (2003) conclude that 'it is impossible to use the DCC test to make any statement on the existence of contagion' (p. 3).

Indeed, the presence of any of one of the two potential shortcomings will severely undermine the DCC test results, however, we disagree that the procedure should therefore be completely dismissed. The key objective of our study is to demonstrate that by incorporating the Markov-Switching Vector Autoregressive (MS-VAR) approach into the overall procedure of the DCC, the two aforementioned problems can be simulatenously addressed. We will revisit the period around the time of the East Asian crises using the daily stock exchange returns of Indonesia, Malaysia, Philippines, Thailand, Singapore, Korea, Hong Kong and Taiwan.

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<sup>3</sup> See also Caporale, Cipollini and Spagnolo (2005).

By incorporating Markov-Switching Vector Autoregression approach, we are able to trace evidences of a significant break or discontinuity in the stock exchange returns of the eight East Asian markets during crisis periods, especially around the time of the 1997 financial crises as compared with the pre-crisis tranquil periods. This is in sharp contrast to the findings of Rigobon (2003), which virtually found no evidence of structural break or contagion at all for the same group of East Asian countries examined in this paper.

As to the reminder of the paper, the roadmap is as follows. Section 2 discusses the basic frameworks of the DCC and the MS-VAR testing procedures. The test results are presented in Section 3. The paper ends with a brief concluding remark (Section 4).

## 2. The Methodologies

### 2.1 Rigobon's Determinant of the Change in Covariance matrix (DCC) test<sup>4</sup>

Suppose that the stock market returns ( $r_{it}$ ) of  $N$  countries at time ( $t$ ) is described by the following latent factor:

$$AR_t = \phi(L)R_t + \Gamma z_t + \varepsilon_t \quad (1)$$

where:

$R_t$  is the vector of endogenous variables of country stock market returns given by  $R_t = (r_{1t} \dots r_{Nt})$ ;  $z_t$  are  $k$  unobservable common shocks;  $\Gamma$  is the matrix containing the coefficients of the common unobservable shocks (the first row is normalized to one);  $\varepsilon_t$  is the vector of country-specific or idiosyncratic shocks which have zero mean ( $E(\varepsilon) = 0$ ) and a diagonal covariance matrix at time  $t$  ( $E(\varepsilon_t' \varepsilon_t)$ ) given by  $\Omega_t^\varepsilon$ ; The unobservable common shocks also share the same properties, i.e., zero mean ( $E(z_t) = 0$ ) and a diagonal covariance matrix at

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<sup>4</sup> The presentation of the DCC procedure in this section follows closely that of Rigobon (2003).

time  $t$  ( $E(z_t' z_t)$ ) given by  $\Omega_t^z$ ; The idiosyncratic shocks and the unobservable common shocks are not correlated ( $E(\varepsilon_t z_t) = 0$ ).

In essence, the DCC test compares the covariance matrix of two subsets of stock market returns data, one for the stock market returns for a tranquil or low volatility period and the other for a turmoil or high volatility period. The DCC test statistic is defined below as the determinant of the difference between the covariance matrices in the turmoil (c) and tranquil (s) period:

$$DCC = \det(\Omega_t^c - \Omega_t^s) = \det(\Delta\Omega_t) \quad (2)$$

It has been shown that if the heteroscedasticity observed in the stock market returns is only in a subset of *either* the idiosyncratic shocks ( $\varepsilon$ ) or the common unobservable shocks ( $z$ ) and the parameters are stable, then the determinant of the change in the covariance matrix is zero. While the determinant will be different from zero in two circumstances: (i) if the coefficients change; (ii) if all the shocks ( $\varepsilon$  and  $z$ ) exhibit heteroscedasticity. Such that, according to Rigobon (2003) for the rejections to be interpreted as parameter instability, it is crucial that at least some shocks are assumed to be homoskedastic.

However, as argued by Billio, Duca and Pelizzon (2003), this is the major problem of the DCC test as one has to know whether the rejections are due to parameter instability alone or the violation of the heteroscedasticity assumption.<sup>5</sup> Another inherent weakness of the DCC procedure is with its ad-hoc process in determining the periods of tranquil and crisis.

These two inherent weaknesses with the DCC test however can arguably be overcome through a non-linear specification of the underlying *data-generating process* of

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<sup>5</sup> As also mentioned in Billio, Duca and Pelizzon (2003), the discussion of this caveat in Rigobon (2003) is not necessary since almost no rejections were found anyway in his paper.

the VAR process. More specifically, this is achieved by employing the Markov switching vector autoregressive (MS-VAR) model developed by Krolzig (1997), to which we will discuss next.

## 2.2 The MS-VAR model

The Markov Switching VAR, or simply, MS-VAR, developed by Krolzig (1997) is a multivariate version of the univariate Markov regime-switching model introduced by Hamilton (1988, 1989). The general idea behind the MS-VAR is that the parameters of a VAR process may not be time-invariant, as assumed by linear models. More precisely, the parameters may be time-invariant as long as a particular regime prevails, but change once the regime changes.

The *regime-generating process* determining which regime  $s_t$  prevails at any point in time, is assumed to follow an ergodic Markov chain with a constant transition probability  $p_{ij}$  of the form:

$$p_{ij} = \Pr(s_{t+1} = j | s_t = i), \quad \sum_{j=1}^2 p_{ij} = 1 \quad \forall i, j \in \{1, 2\} \quad (3)$$

At the same time, the *data generating process* of the MS-VAR process can be considered as a generalisation of the basic finite order VAR model of order  $L$ , which can be used to extend equation (1) as:

$$AR_t = \phi(L)R_t + \Gamma z_t + Z(s_t)\varepsilon_t \quad (4)$$

where  $s_t$  is the unobservable regime. Maximum likelihood estimation of equation (4) yields the 'smoothed probabilities', which represents the *ex post* inference about the system being in regime  $i$  at date  $t$ .

Furthermore, an observation is assigned to regime 1 if  $\Pr(s_t = 1 | \Delta R_t) > 0.5$ , and to regime 2 otherwise. In the above specification, the idiosyncratic shocks ( $\varepsilon_t$ ) are pre-



multiplied by a regime-dependent matrix  $Z(s_t)$ . Thus, the variance-covariance matrix  $\Omega^\varepsilon(s_t)$  is regime dependent:

$$\begin{aligned}\Omega^\varepsilon(s_t) &= E[Z(s_t)\varepsilon_t'\varepsilon_t Z'(s_t)] = Z(s_t)E(\varepsilon_t'\varepsilon_t)Z'(s_t) \\ &= Z(s_t)I_2 Z'(s_t) = Z(s_t)Z'(s_t)\end{aligned}\quad (5)$$

In other words, by directly allowing the variance-covariance matrix of the idiosyncratic shocks alone to be regime-dependent or with heteroscedastic errors, cases of rejections of the null of parameter stability, i.e., when the determinant of the change in the covariance matrix is different from zero, can now be conveniently attributed to the existence of parameter instability in stock market returns data (Equations 4-5).<sup>6</sup> At the same time, the use of the MS-VAR obviates the arbitrary or ad-hoc selection of the crisis period to one that endogenizes the process of separating crisis from non-crisis periods, hence avoiding allegations of sample selection bias which standard analyses of contagion are subjected to.<sup>7</sup>

### 3. Empirics

#### 3.1 Data

The data series for daily stock market returns denominated in US dollars are sourced from Datastream and covered the period from January 1997 to January 1998 for Hong

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<sup>6</sup> This is also another way of saying that the common unobservable shock ( $z$ ) is homoskedastic for the rejections to be interpreted as parameter instability.

<sup>7</sup> For instance, Billio and Pelizon (2003) clearly documented that inferences based on heteroscedasticity-adjusted conditional correlation coefficients, with the choice of the crisis and tranquil windows exogenously determined, are highly sensitive to varying lengths of the tranquil and crisis windows. See also Boyer (1999), Dungey and Tambakis (2003) and Pericoli and Sbracia (2003) for recognition of this problem with previous studies on contagion.

Kong, Indonesia, Malaysia Philippines, Singapore, Korea, Taiwan and Thailand.<sup>8</sup> Figures 1a-1b show the daily time series fluctuations of these eight East Asian stock market returns for the entire period examined in this paper. By just a simple eyeballing of the figures, the stock markets of these countries experienced significantly more volatilities, especially starting around mid-1997.

Prior to conducting any testing on the data sets, the unit-root properties of the series are examined. Table 1 reports both descriptive statistics as well as ADF unit roots tests of the stock market returns data. All stock market returns (in log first differences) are found to be stationary (or  $I(0)$ ).<sup>9</sup>

### 3.2 Empirical Testing

In its bare essence, the Rigobon (2003) DCC test is implemented by comparing the covariance matrices of stock market returns for two sub-samples, namely one for a low-volatility or a tranquil period and another for a high-volatility or a crisis period. The covariance matrices for the two sub-samples are arrived by estimating a linear, reduced-form VAR using equation (1) and the residuals are recovered from the estimation. Once this is done, the reduced-form residuals are split according to a pre-determined window and the determinant of the change or difference in covariance (DCC) matrices for the two sub-samples is computed. The distribution of the DCC is obtained by bootstrap.

The computation of the bootstrap proceeds by generating several covariance matrices for each window using the asymptotic distribution of the covariance matrices, and

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<sup>8</sup> The choice of these countries basically follows the same eight Asian countries that Rigobon (2003) analysed to conduct the DCC test on a multivariate (regional) framework.

<sup>9</sup> The KPSS Unit-Root tests have also been conducted and the results are consistent with those of the ADF reported in Table 1. For the sake of brevity, we do not report the KPSS results.

computes the determinant of the change for each draw. If the determinant is different from zero, then the stability of the parameters is rejected. In this test a certain  $p$ -value is computed using the mass that are above zero. If this mass is very small, or very large, then most of the distribution is on one of the sides and the test should be rejected.<sup>10</sup>

Our empirical works start with the basic approach of the linear unrestricted VAR of the DCC procedure, employed in Rigobon (2003). However, as discussed, the main contribution of the paper is on the application of the Markov regime-shifts in the estimation of an unrestricted VAR within the DCC procedure (Equation (4)) to address the potential problems with sample period selection and with the heteroscedasticity assumption.

### **3.2.1 Linear VAR-DCC test**

We simply follow Rigobon (2003) in defining the windows for which the covariance matrices are estimated. The low-volatility or tranquil period is defined as the 6 months prior to Thailand's devaluation. As indicated in column [1] of Table 2, two distinct crises periods, originated in Hong Kong and Thailand, and the full sample observations are reported.<sup>11</sup> Columns [2-3] are the dates for the tranquil period, which is then followed by the crisis periods (columns [4-5]). We report the distribution of the mass below zero in column [6] and the significance of the parameter stability is reported in the last column.

From the information provided in the last two columns, the hypothesis that the coefficients are stable cannot be rejected, suggesting no evidence of contagion reported during all two different crises periods and the full sample period of the East Asian crisis for

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<sup>10</sup> In other words, as also clarified in Rigobon (2003), if the mass is too small or too large this implies the determinant is different from zero. Thus, conclusions can already be made by simply observing either the mass above or below zero.

<sup>11</sup> Note that the Korean crisis falls within that of the crisis in Hong Kong. Hence, we do not separate the two cases of crises.

the case of eight countries observed. These findings are consistent with those of Rigobon (2003).<sup>12</sup>

### **3.2.2 Markov Switching VAR-DCC test**

Next task is to discuss the finding of the DCC test with the estimation of the covariance matrices done endogenously via a Markov-switching VAR (Table 3). Instead of breaking the observations into two pre-determined sample periods, the MS-VAR procedure considers the full sample observation and endogenously separate the observations into those of tranquil and crisis sub-samples. Columns [1] and [2] report the beginning and end of full sample estimation period. In column [3] we report the mass below zero of the DCC test with Markov switching VAR. As earlier mentioned, this is used to make inference on the stability of the parameters.

A number of interesting findings are worth highlighting. For the full sample period, which includes the crises in Hong Kong, Korea, and Thailand, the hypothesis of stability of the parameters can be rejected as the mass below zero is marginally above 90%.<sup>13</sup> A similar finding, but at a higher significance level of 10 percent, is reported when we consider only the crisis period in Hong Kong.<sup>14</sup> However, when we focus on the crisis period in Thailand, we cannot reject the hypothesis of stability of the parameters. In summary, our MS-VAR DCC test results suggest that there are indeed evidences of contagion during the different episodes of financial crises in East Asia during the late 1990s. In fact, Forbes and

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<sup>12</sup> See Table 5, p. 275 of Rigobon (2003).

<sup>13</sup> This is a rejection only at the 20% confidence.

<sup>14</sup> We also tried different robustness test where we introduce interest rates as controls, changes in the starting sample period as well as in the end-sample period did not change the qualitative results of the DCC test version from a Markov switching VAR, wherein we find rejections of the null of stability at either at the 20% or stronger.

Rigobon (2002) emphatically made the observation that during the onset of the East Asian crisis, for instance, American and British newspaper and periodical accounts paid little attention to the earlier movements in the Thai and Indonesian markets until only the sharp decline in the Hong Kong stock market that discussions about the possibility of contagion to the rest of the world from the crisis quickly started.<sup>15</sup>

#### **4. Brief Concluding Remarks**

The basic idea that cross-market correlations rise following an increase in volatility, explored initially by King and Wadhwani (1990), has been the primary foundation of recent works on contagion. In attempts to deal with the common problems in measuring contagion, namely of heterocedasticity, omitted variables, and simultaneity biases, Rigobon (2003) proposes the DCC procedure. The measures of contagion introduced by most of early studies, including the DCC, have however suffered from the presence of ambiguous identification of periods of crisis and tranquil (Pericoli and Sbracia (2003) and Billio, Duca and Pelizzon (2003)). Furthermore, the ad-hoc process of selecting the crisis period has also been shown to undermine the basic heteroscedasticity assumption of the error term, leading to more ambiguity in interpreting the final result of the DCC.

Our study demonstrates that the application of the MS-VAR methodology can further improve the capability of the DCC procedure by specifically addressing its potential shortcomings, i.e., its assumption on heterocedasticity and its pre-determined choice of sub-sample periods. In contrast to the findings of the original DCC methodology (Rigobon (2003)), our empirical results show that the sizable increase in the volatility of stock returns of selected East Asian economies during the period of the late 1990s, which was associated

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<sup>15</sup> Caporale, et al. (2005) makes the same conclusion, see p. 486.

with one of the major financial crises in recent history can be rightfully ascribed to contagion and do not just reflect higher rates of interdependence across most stock markets in the region. In other words, there is evidence to conclude in this paper that the propagation of shocks shifted significantly starting with the onset of the sharp decline in the Hong Kong stock market.

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**Table 1**  
**Descriptive statistics and unit root tests**

	Mean	Standard deviation	ADF
Hong Kong	-0.11	1.55	-4.45* (8)
Indonesia	-0.55	3.61	-7.07* (6)
Korea	-0.26	2.96	-4.83* (6)
Malaysia	-0.44	2.13	-6.73* (6)
Philippines	-0.31	1.77	-4.52* (10)
Singapore	-20	1.41	-7.05* (6)
Taiwan	-0.02	1.15	-5.52* (6)
Thailand	-0.40	2.02	-5.24* (6)

*Notes:* The number in parentheses next to the ADF statistic is the number of lags selected using the SIC. The 5% critical value for the ADF test is -2.87.

\* denotes stationary.

**Table 2**  
**DCC results from linear VARs**

	Tranquil window		High volatility or Turmoil Window		Below zero	Significance
	Starts	Ends	Starts	Ends		
<b>Hong Kong crisis period</b>	1-2-1997	6-2-1997	10-27-1997	11-28-1997	0.621	N
<b>Thailand crisis period</b>	1-2-1997	6-2-1997	6-10-1997	8-29-1997	0.657	N
<b>All</b>	1-2-1997	6-2-1997	6-10-1997	1-30-1998	0.404	N

*Notes:* the tranquil and turmoil windows follow that of Rigobon (2003); N stands for the non-rejection of the null of parameter stability.

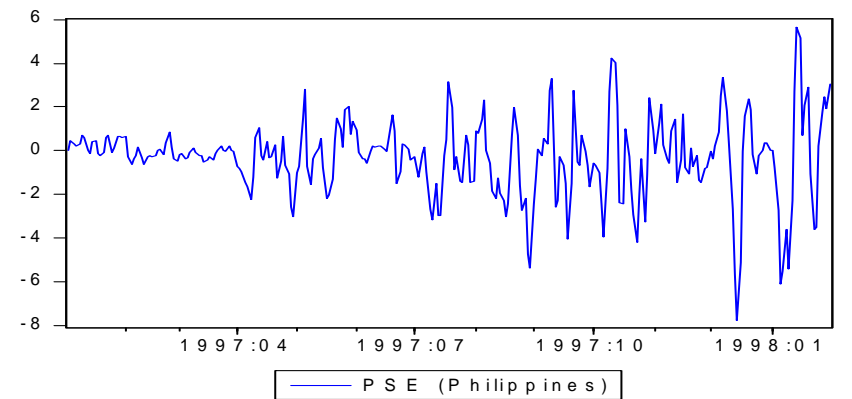
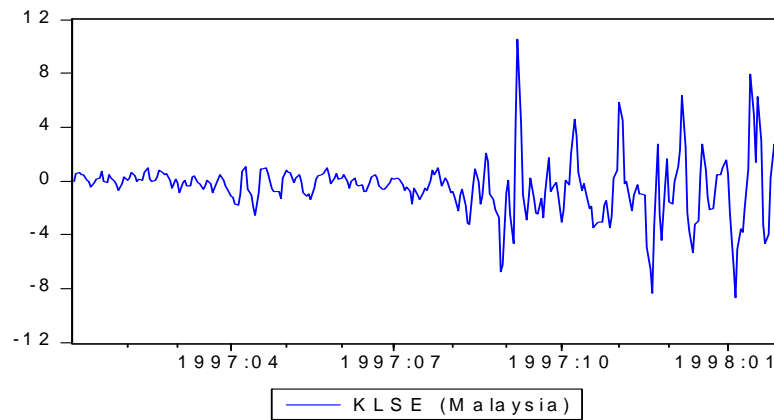
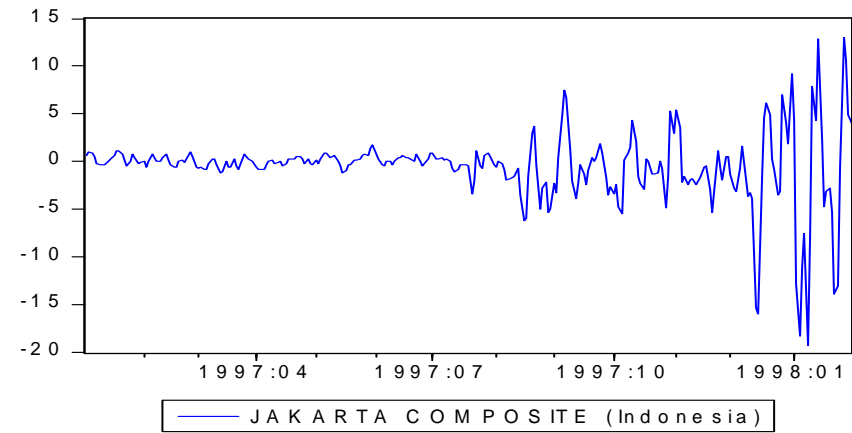
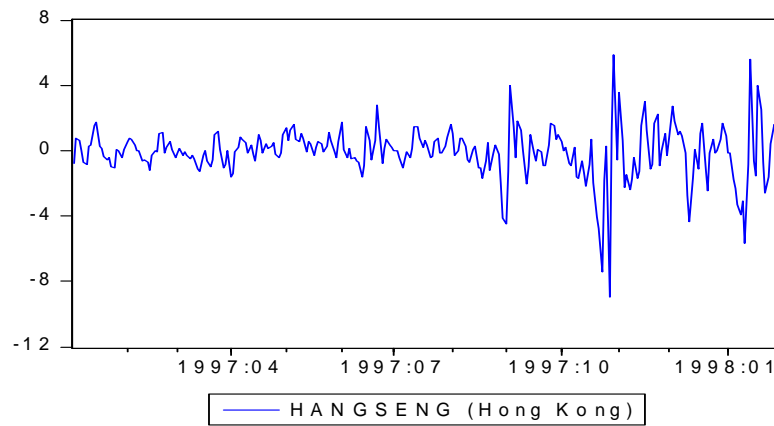
**Table: 3**

**DCC results from Markov-switching VAR**

	<b>Start Period</b>	<b>End Period</b>	<b>Below zero</b>	<b>Significance</b>
<b>All<sup>a</sup></b>	1-2-1997	1-30-1998	0.91	<b>Y</b>
<b>Hong Kong</b>	1-2-1997	11-28-1997	0.04	<b>Y</b>
<b>Thailand</b>	1-2-1997	8-29-1997	0.78	<b>N</b>

*Notes:* <sup>a</sup> / All corresponds to the entire sample period considered in Rigobon (2003), including the crises in Korea, Hong Kong, and Thailand. With the application of the MS-VAR, the arbitrary choice of end-tranquil window and start of high-volatility window are avoided in view of the full sample estimation and endogenous determination of tranquil and crisis periods. Y stands for the rejection of the null of parameter stability, and N stands for the non-rejection of parameter stability.

**Figure 1a**  
**The East Asian Stock Market Indices**



**Figure 1b**  
**The East Asian Stock Market Indices**

